

## Geologic Hazard Assessments Subactivity

| Subactivity                  | FY 2000<br>Estimate | Uncontrol.<br>& Related<br>Changes | Program<br>Changes           | FY 2001<br>Budget<br>Request | Change<br>from<br>FY 2000 |
|------------------------------|---------------------|------------------------------------|------------------------------|------------------------------|---------------------------|
| <b>Earthquake Hazards</b>    | <b>43,893</b>       | <b>+867</b>                        | <sup>(1)</sup> <b>+2,600</b> | <b>47,360</b>                | <b>+3,467</b>             |
| Volcano Hazards              | 17,181              | +284                               | +250                         | 17,715                       | +534                      |
| Landslide Hazards            | 2,580               | +48                                | <sup>0</sup>                 | 2,628                        | +48                       |
| Global Seismographic Network | 3,464               | +33                                | 0                            | 3,497                        | +33                       |
| Geomagnetism                 | 1,993               | +43                                | 0                            | 2,036                        | +43                       |
| Total Requirements \$000     | 69,111              | +1,275                             | +2,850                       | 73,236                       | +4,125                    |

<sup>1</sup> See Program Change section for details on Safer Communities (+\$2,600)

## Earthquake Hazards

### Current Program Highlights

The USGS Earthquake Hazards Program helps reduce deaths, injuries, and property losses from earthquakes through understanding of their characteristics and effects and by providing the information and knowledge needed to mitigate these losses.

The USGS Earthquake Hazards Program is a major component of the National Earthquake Hazards Reduction Program (NEHRP) authorized by P.L. 105-47. The program coordinates its activities with the three other principal NEHRP agencies: FEMA, NSF, and NIST. The USGS has the responsibility, within NEHRP, to identify and characterize earthquake hazards, to monitor seismic activity, and to conduct research in support of earthquake hazard assessments and loss reduction practices and strategies.

The USGS provides the professional expertise, technical resources, geographic extent, response capability, and the established reputation of scientific excellence and objectivity needed to address the responsibilities identified by NEHRP. Federal, State, and local government agencies, architects and engineers, insurance companies and other private businesses, land use planners, emergency response officials, and the general public all rely on the USGS for earthquake hazard information and knowledge. This information is used to refine building codes, develop land use strategies, safeguard lifelines and critical facilities, develop emergency response plans, and take other precautionary actions to reduce losses from future earthquakes.

The USGS contributes to earthquake hazard mitigation strategies by estimating and describing the likelihood and potential effects of moderate to large earthquakes in high-risk regions of the U. S. and by transferring this knowledge to people and agencies that can reduce the impact of a significant earthquake. The USGS also responds to earthquake emergencies by rapidly characterizing the probable size and extent of damage, assessing the continuing risks from

aftershocks and related ground-motion and ground-failure hazards, and facilitating the work of response officials.

The program provides critical earth-science information for understanding earthquakes and for identification and quantification of potential earthquake hazards throughout the United States. This information is used to design and improve strategies for reducing losses from future earthquakes and to provide the knowledge needed to respond to earthquake emergencies. The USGS supplies information on earthquake mitigation strategies to a large and diverse public and private user community.

**External Cooperative Agreements and Grants** -- The USGS Earthquake Hazards Program supports a competitive, peer-reviewed, external program of cooperative agreements and grants that enlists the talents and expertise of State and local government, the academic community, and the private sector. The investigations and activities supported through the external program are closely coordinated with and complement the internal USGS program efforts. In general, routine monitoring efforts are supported through three-year cooperative agreements, research efforts are supported through one to two year grants. In FY 2000, 18 cooperative agreements were funded to support regional seismic monitoring efforts in various parts of the country. A total of 112 research grants were supported, 82 with universities and colleges, 10 with State Geological Surveys, and 20 with private sector companies (see chart below). Many of the external projects are co-funded with other agencies and sources, leveraging the effect of USGS support. External program activities include: monitoring and locating earthquakes by regional seismographic networks, mapping seismic hazards in metropolitan areas, developing credible earthquake planning scenarios including loss estimates, defining the prehistoric record of large earthquakes, investigating the origins of earthquakes, and improving methods for predicting earthquake effects. By involving the external community, the USGS program increases its geographical and institutional impact, promotes earthquake awareness across the Nation, encourages the application of new hazards assessment techniques by State and local governments and the private sector, and increases the level of technical knowledge within State and local government agencies. During FY 1997 through FY 2000, Congress provided \$6.0 million annually for competitively awarded earthquake research grants. The FY 2001 request maintains this same level of funding.

### COOPERATIVE AGREEMENTS

|                                       |                                   |
|---------------------------------------|-----------------------------------|
| Boston College                        | University of Memphis             |
| California Institute of Technology    | University of Nevada - Reno       |
| Central U.S. Earthquake Consortium    | University of Oregon              |
| Columbia University                   | University of South Carolina      |
| Massachusetts Institute of Technology | University of Southern California |
| Oregon State University               | University of Utah                |
| St. Louis University                  | University of Washington          |
| University of Alaska                  | Virginia Tech                     |
| University of California - San Diego  | University of Nevada - Reno       |

## GRANTS

|   |   |
|---|---|
| Battelle Memorial Institute                 | University of Arkansas (2)                      |
| Brown University                            | University of California - Berkeley (8)         |
| California Institute of Technology (4)      | University of California - Davis                |
| Carleton University (3)                     | University of California - Los Angeles (2)      |
| Central Washington University (2)           | University of California - San Diego (4)        |
| Columbia University                         | University of California - Santa Barbara (2)    |
| GEO-HAZ Consultants, Inc. (2)               | University of California - Santa Cruz           |
| Georgia Institute of Technology             | University of Colorado                          |
| Harvard University (3)                      | University of Illinois - Urbana/Champaign       |
| Harvard-Smithsonian Center for Astrophysics | University of Kentucky                          |
| Humboldt State University                   | University of Memphis (4)                       |
| M Tuttle & Assoc (3)                        | University of Nevada - Reno (2)                 |
| Massachusetts Institute of Technology       | University of North Carolina (2)                |
| Nevada Bureau of Mines and Geology          | University of Oklahoma                          |
| Oregon DOGAMI                               | University of Puerto Rico (3)                   |
| Oregon State University (3)                 | University of South Carolina                    |
| Pacific Geoscience Centre (2)               | University of Southern California (3)           |
| Piedmont Geosciences Inc                    | University of Texas - Austin (3)                |
| Princeton University                        | University of Texas - El Paso (3)               |
| Rensselaer Polytechnic Institute            | University of Utah                              |
| Risk Engineering Inc.                       | University of Washington (3)                    |
| San Diego State University (3)              | University of Wisconsin                         |
| San Francisco State University              | URS Greiner Woodward Clyde                      |
| St. Louis University                        | URS Greiner Woodward Clyde Federal Services (6) |
| Stanford University (2)                     | Virginia Polytechnic Institute (3)              |
| State University of New York - Buffalo      | Washington Department of Natural Resources      |
| Texas A and M University (2)                | William Lettis and Associates (5)               |
| University of Alaska                        |   |

**Products for Earthquake Loss Reduction** -- USGS seismic maps for the United States are being used to develop new, unified building codes for the United States. These maps are in digital format and give the maximum severity of ground shaking that can be expected during time periods of 50, 100, and 250 years, and are also being used to predict earthquake losses and to define insurance risks. A new seismic hazards map for Alaska was produced in 1998. In 1999, a new map for Hawaii was produced. Similar maps are being produced for Puerto Rico and the U. S. Virgin Islands, and efforts will begin for maps of American Samoa and Guam. Periodic review and updating of such maps to incorporate new information are among the highest priorities for the USGS. Development of these maps involves extensive consultation with earthquake researchers, engineers, and State and local government representatives. The maps integrate geologic mapping; fault locations, fault slip rates, and earthquake recurrence intervals; and analyses of crustal deformation, ground-motion patterns, and recent seismicity. The USGS is working to improve the base of geologic data for preparation of the next generation of seismic hazard maps.

**Earthquake Hazards Assessments in Urban Areas** -- The USGS is generating products that address the hazards in high to moderate risk urban areas, where the population and risks are

greatest, such as the San Francisco Bay area, Los Angeles, Seattle, Salt Lake, Memphis, and Charleston, South Carolina. Earthquake shaking scenarios are being developed for public planning, and modeling of ground motion is being provided for engineering applications. In conjunction with these products, the USGS conducts workshops to ensure the proper transfer of knowledge and to help design effective mitigation.

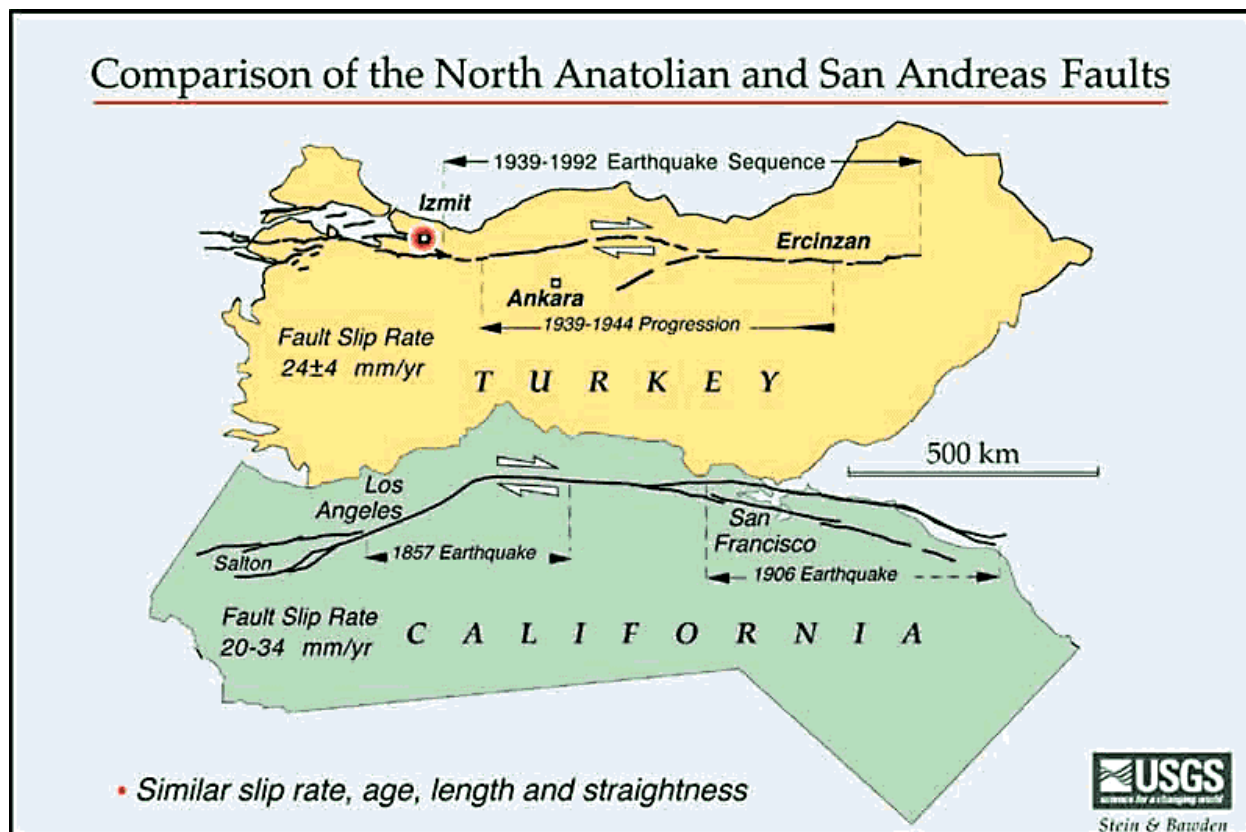
**Regional Earthquake Monitoring** -- The USGS and cooperating universities operate regional seismic networks in areas of high seismicity. Data from all U.S. seismic networks are used to monitor active tectonic structures in much greater detail than is possible with the national scale network. Each region has a local data center where the data are processed and regional catalogues of earthquakes are produced. These data centers serve as local distribution points for information about earthquakes, relaying earthquake data in real time to the National Earthquake Information Center as well as to other regional networks. Data centers also provide information about regional earthquake mitigation practices, and those data centers located at universities provide a training and research facility for students.

**Monitoring Strong Motions Due to Earthquakes** -- Conventional seismometers used in earthquake monitoring networks cannot accurately record strong ground and building motions caused by large, nearby earthquakes. Yet this technical data is extremely valuable for the design of earthquake resistant buildings and other structures. Through the National Strong Motion Program the USGS maintains about 840 strong motion recorders in 35 States and territories. The strong motion data show the amplitude, frequency content, and duration of strong accelerations caused by an earthquake. These parameters are direct inputs to computer models and scale models of structures to test their performance under realistic earthquake shaking.

**Monitoring Changes in Shape of the Earth's Surface** -- Geodetic networks provide essential information about movement of the land surface near faults and earthquake source zones. The USGS is working with universities and local agencies to conduct geodetic investigations using the global positioning system (GPS) and laser ranging surveys. A dense network of continuous GPS stations is being installed, in cooperation with NASA, NSF, and Scripps University, to determine the distribution of long-term crustal deformation and the spatial and temporal variations of the strain field in southern California. During the next two years, with funding support from USGS cooperators, new stations will be sited and installed, communications and data retrieval operations will be developed, and processing and archiving centers will be established. The USGS has a lead role in operation of the network, with responsibility to maintain stations and download data. In addition, the USGS is investigating a new satellite technology, Interferometric Synthetic Aperture Radar (InSAR), that has the potential of quickly and accurately providing large aerial maps of pre- and post-earthquake land deformation. Work is underway to develop computational tools necessary to efficiently analyze, interpret, and model InSAR data. The InSAR results in southern California will be used to augment, check, and if necessary correct the independent GPS measurements.

**Post-Earthquake Investigations** -- The USGS responds to large domestic earthquakes and to some foreign earthquakes by deploying portable seismic and geodetic instrumentation, conducting detailed geologic field investigations, and evaluating damage patterns in relation to geologic conditions and effects. These investigations provide essential information during and immediately after the emergency and an opportunity to make substantial advances in our understanding of earthquake geology and engineering. In FY 2000 post-earthquake investigations will include follow-up studies of three large earthquakes which occurred in 1999: the magnitude 7.4 and 7.1 earthquakes in Turkey and the magnitude 7.6 earthquake in Taiwan.

The Turkey earthquakes occurred on the North Anatolian fault, which is an excellent analog to the San Andreas. Studies will take advantage of the long history of recorded earthquake activity in Turkey (1500 years versus 150 years in California) to address how stress is transferred along the fault via earthquake activity. These studies should provide important insights into the behavior of strike-slip faults in general and will be particularly relevant to studies of the San Andreas fault. The earthquake in Taiwan was recorded on a dense network of digital accelerographs, capable of recording the ground motion on scale. As a result, an unprecedented data set exists that can be used to study site and building response to strong ground motion. Ultimately these studies will lead to advancements in building codes in regions proximal to active fault zones.



**Additional Earthquake Research** -- The USGS conducts research that has significant potential for breakthrough discoveries in earthquake hazard assessment and mitigation. The research is interdisciplinary, peer-reviewed, and coordinated with external partners through grants and cooperative agreements. Research results are incorporated rapidly in USGS earthquake loss reduction products.

A major focus of USGS earthquake research is in understanding earthquake occurrence in space and time. Ongoing USGS investigations seek to understand the physical conditions for earthquake initiation and growth; processes of earthquake triggering; how individual faults in the same region interact; why some faults slip slowly without generating earthquakes while others generate earthquakes; and the factors that control variations in recurrence intervals of earthquakes along the same fault.

Improving current techniques for forecasting the effects of strong ground motion will greatly improve seismic hazard maps for urban regions and is critical to cost-effective earthquake hazard mitigation. USGS earthquake research in this area addresses how complexities in the earthquake source, earth's crust, and near-surface soils and deposits influence seismic wave propagation and strong ground motion. Identifying and understanding the behavior of weak liquefiable sediments is also a priority. Research on ground failure in collaboration with structural and geotechnical engineers will lead to improved design of earthquake-resistant infrastructure.

USGS earthquake research also continues to address the problem of short-term warnings in the days or hours before damaging earthquakes. Well-documented geologic and (or) hydrologic signals preceded the Loma Prieta and Kobe earthquakes, warranting thorough investigation of these phenomena. The ongoing USGS earthquake prediction experiment at Parkfield, California, may permit not only the recording of pre-earthquake signals, but also the possibility of understanding their origin. USGS will continue research in the forecasting of earthquake aftershocks, which is of great value to citizens and public safety officials in the aftermath of large earthquakes.

### Recent Accomplishments

**Earthquake Probabilities for the San Francisco Bay Area** -- On the basis of research conducted since the 1989 Loma Prieta earthquake, the USGS released the results of a Working Group study giving a 70% probability of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking the San Francisco Bay region before 2030. This report, released in October of 1999, is far more comprehensive than the earlier, 1990 probability estimate. One of the major differences is that the new study analyzed five additional faults (Calaveras, Concord, Green Valley, Mount Diablo, and Greenville faults) compared to the 1990 study which only considered the San Andreas and Hayward-Roger's Creek faults. Additionally, the study did not restrict the assessment to earthquakes magnitude 7 or greater, as the 1990 report had done, but instead considered the potential for smaller earthquakes. This change was implemented so that an event comparable to the magnitude 6.7 Northridge earthquake, which killed 57 people and caused more than \$20 billion in damage, would be taken into account. The Working Group's assessment of the likelihood of moderate sized earthquakes in the Bay region found an 80% chance of one or more magnitude 6 to 6.6 quakes occurring before 2030. Conclusions from the working group's 2-year effort are presented in USGS Circular 1189 "Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030." These results were formally presented at a conference of the Association of Bay Area Governments held to commemorate the 10<sup>th</sup> anniversary of the Loma Prieta earthquake.

**Hector Mine Earthquake** -- The M7.1 Hector Mine earthquake occurred at 2:46 a.m. local time on October 16, 1999. The event was located in a remote, sparsely-populated part of California's Mojave desert, approximately 47 miles east-southeast of Barstow and 32 miles north of Joshua Tree. The earthquake occurred on the Lavic Lake fault, one of a series of closely spaced, northwest-trending, right-lateral strike-slip faults that traverse this portion of the Mojave Desert. Given that the Lavic Lake fault had not produced a large earthquake within the last 10,000 years, USGS scientists are conducting research to see if this kind of earthquake behavior is typical of the region or is just coincidental. The primary concern is their influence on the San Andreas fault, which is a major threat to the populated urban areas of Los Angeles, San Bernardino, and Palm Springs. The M7.1 Hector Mine event triggered small earthquake

activity as far south of the California-Mexico border, and some of these events occurred close to the southern end of the San Andreas fault.

**Real-time Assessment of the Hector Mine Earthquake** -- Although the Hector Mine earthquake was not noteworthy from a disaster standpoint, the event was significant as a test of the newly upgraded Southern California seismic network known as TriNet. Following the 1994 Northridge earthquake, FEMA funded a three-way effort among Caltech, the California Division of Mines and Geology, and the USGS to upgrade the antiquated southern California seismic network with digital, real-time, broad-band recording capability. Some of the network upgrades were achieved prior to the Hector Mine event, making TriNet the most sophisticated regional seismic network in the United States. With this state-of-the-art equipment in place, the location of the Hector Mine earthquake was pinpointed and magnitude measured within two minutes of the origin of the event. A map showing the distribution and severity of strong ground shaking was released within six minutes. Such immediate determination of critical earthquake parameters is essential for emergency response efforts, and thus the TriNet performance during Hector Mines provides a proof of concept for a real-time earthquake monitoring capability.

Such rapid assessment of ground shaking enables emergency response officials to immediately pinpoint the location and extent of damage and determine how to allocate scarce response-and-recovery resources. The location of greatest ground shaking and surface deformation is not always concentrated about the epicenter of an earthquake. In both the 1989 Loma Prieta and 1999 Kocaeli, Turkey, earthquakes, for example, significant damage occurred tens of kilometers away from the epicenter, due primarily to the distribution of poorly consolidated deposits which amplified strong ground motion. Therefore, without a means of quickly and systematically surveying the intensity of ground shaking following an earthquake, areas of significant damage could easily be overlooked. Emergency managers thus require more than the location and magnitude of an event – they need to know how intensely the ground shook and what the likelihood is of significant damage.

**Seismic Network Integration** -- The USGS operates a U.S. National Seismic Network (USNSN) consisting of 56 broad-band instruments distributed across the United States. The USGS and cooperating universities also operate regional seismic networks (RSNs) in areas of high seismicity. Data from all U.S. seismic networks are used to monitor active tectonic structures in much greater detail than is possible from the USNSN alone. Each regional network is responsible for cataloging earthquakes and serving as the distribution point for information on earthquakes and earthquake mitigation practices.

In the past year, the USGS Earthquake Hazards Program has made significant progress in integrating the regional and national seismic networks into a National Seismic System with seismic monitoring and data distribution system for the Nation. As a result, each of the USGS-supported regional seismic networks is now able to communicate with adjacent networks and with the USNSN in real time, thereby greatly improving performance at the regional and National level. Presently, almost 900 channels of seismic trace data flow into the National Earthquake Information Center (NEIC) in Golden, Colorado, from the regional and national networks. Likewise, the majority of seismic data produced by the RSNs is available on demand at the NEIC. Thus, the USGS now has the infrastructure in place to share data across networks in real time and to coordinate rapid earthquake response at the regional and National levels. In addition, this network integration provides back-up reporting capability should a regional network be damaged in a significant earthquake. The system also allows for the beginnings of a central repository combining significant RSN/USNSN data for all located earthquakes. Development of this system has been well coordinated between the NEIC and the regional

networks, and has also benefited from the contributions of several states, federal agencies, and private sector companies.

**Foreign Earthquake Response** -- In recent months, the USGS responded to two large foreign earthquakes, the magnitude 7.4 Kocaeli, Turkey, earthquake which occurred on August 17, 1999, and the magnitude 7.6 Taiwan earthquake which occurred on September 20, 1999. With respect to Turkey, the USGS dispatched geologists, geophysicists, and structural engineers to assist Turkish scientists at the Kandilli Observatory to document the damage and study the rupture. The team deployed instruments from Istanbul to Adapazarı over a two-month period. The instruments were to record strong ground motion from aftershocks and thereby determine the level of site amplification resulting from local soil conditions. These data, in turn, provide insights into how much of the earthquake destruction was caused by strong ground motion and how much was caused by construction practices. Information on site amplification is also important for revising building codes and for determining where rebuilding efforts should be focused. These are all critical contributions to any post-earthquake reconstruction effort. Research in Turkey was coordinated with Turkish colleagues and with other U.S. researchers including the National Institute of Standards & Technology, the National Science Foundation, and the Earthquake Engineering Research Institute. Results from the Turkey post-earthquake investigations were published in January 2000, in Circular 1193 entitled: "The Kocaeli, Turkey, earthquake of August 17, 1999."

The Taiwan response effort had a somewhat different focus. The Taiwan earthquake spawned major landslide activity in the mountainous regions of the island. Efforts were directed at systematically identifying, classifying, and cataloguing landslides, and using this information to forecast potential areas susceptible to future landslide activity. The Taiwan earthquake was also unique in terms of being recorded on-scale by a network of state-of-the-art seismographs densely distributed across the island. As such, the earthquake offers a first-time opportunity to study on-scale instrument recordings of strong ground motion in the earthquake zone. The USGS is working with Taiwan scientists at the Central Geological Survey to study these instrument responses and assess the level of ground shaking particularly in the vicinity of the earthquake's epicenter. The third and final component of post-earthquake cooperative studies with the Central Geological Survey was in the area of paleoseismology and studies of long-term seismic patterns in the Taiwan region. The USGS is well experienced at using the geologic record to determine earthquake recurrence rates and magnitude of slip during past earthquake ruptures. USGS scientists are working closely with geologists from the Central Geological Survey of Taiwan to share this expertise and help establish a long-term record of seismicity that can serve as a basis for future earthquake hazard assessments of Taiwan.

**Earthquake Studies in the Los Angeles Basin** -- The Los Angeles region is underlain by a network of active faults, including many that are deep and do not break the Earth's surface. These hidden faults include the previously unknown "blind" thrust fault responsible for the devastating January 1994 Northridge earthquake, the costliest quake in U.S. history. So that structures can be built or strengthened to withstand the quakes that are certain to occur in the future, the Los Angeles Region Seismic Experiment II (LARSE II) was designed to locate hidden earthquake hazards beneath the region to help scientists determine where the strongest shaking will occur.

LARSE II used sound waves traveling beneath the Earth's surface to produce images of these structures, similar to the method used to create an ultrasound image. During the major "active" part of this experiment in late October 1999, sound waves were generated by explosive charges

detonated beneath the surface in specially-drilled boreholes. The sound waves were received by over 1400 portable seismographs.

**Integrated Earthquake Studies in the Central United States** -- Four large earthquakes of near magnitude 8 with thousands of aftershocks struck the central Mississippi Valley during the winter of 1811-1812. This region continues to have the highest level of seismicity in the United States east of the Rocky Mountains. The Central United States Earthquake consortium (CUSEC) has been supported by FEMA to allow the emergency managers of Missouri, Illinois, Indiana, Kentucky, Tennessee, Mississippi, and Arkansas to jointly address earthquake response problems. Similarly the USGS Earthquake Hazards Program supports the CUSEC State Geologists to work together to assess earthquake hazards in the region. This cooperation has resulted in the publication of a map showing the relative potential for ground shaking and ground failure (liquefaction) for the seven-state area. The map also shows the infrastructure lifelines (interstate highways and pipelines) for the regions and how they are threatened by vulnerable soil conditions. In addition to the earthquake hazard information it conveys, the process of producing the map shows how federal support can allow State agencies to work together to address a common problem in a coordinated and consistent manner. The map was published by the USGS Mid-Continent Mapping Center.

**Silicon Valley Earthquake Studies** -- Urban areas built on shallow geologic basins filled with weakly consolidated material are particularly vulnerable to earthquake shaking. This was the cause of most of the earthquake damage in Mexico City in 1985 and the terrible loss of life (25,000) in Armenia in 1988. For the past two years the USGS, with partial funding through a Cooperative Research and Development Agreement (CRADA) with the Pacific Gas and Electric Company, has operated a dense, portable array of seismometers in the Santa Clara basin near San Jose, California. Almost all of the array stations triggered during an earthquake sequence in Nevada in August 1999 that was 250 miles away. This information was used to determine how the geologic structure of the Santa Clara basin amplifies and extends the duration of strong seismic shaking. These and similar studies in other urban areas in similar geologic settings will vastly improve our understanding of the variation of ground motions and our prediction of shaking from future earthquakes.